

## SOUTHWEST CENTER FOR ADVANCED STUDIES

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Laboratory Studies of Electron Collision Frequency

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Significant progress toward the proposed objectives has been made in the following areas.

Adaptation of Vacuum Facility for Maximum Efficiency

The vacuum facility pictured in Figure 1 was designed and built at the Southwest Center for Advanced Studies, being completed when these collision frequency studies were initiated. It has proven to be a very practical system. The facility is also required for other experimental studies, and therefore, two additional end plates were built so that experiments can be changed in a minimum time. It is now possible to mount an experiment on one set of end plates while another experiment is being conducted in the vacuum; change-over can be completed in a few hours, and thus the percentage utilization of the vacuum chamber can be quite high.

Attainment of a Stable Low-Density Plasma

A stable plasma with useful parameters has been produced in the vacuum chamber. The experimental arrangement is shown in Figure 2. Potentials between -200 volts and -4000 volts are applied to the sharply-pointed stainless steel cathodes in each bell jar. The end plate is held at ground potential and a stable discharge is produced in the bell jar. The plasma diffuses through a



hole in each end-plate to produce a low-density plasma inside the main vacuum chamber. This discharge works well in nitrogen, helium, and air through a pressure range of several microns to several hundred microns. Other gases have not been tried.

Preliminary measurements indicate that no electric fields are present in the chamber and that the electron density of the plasma can be varied between a few electrons per  $\text{cm}^3$  and approximately  $10^6$  electrons per  $\text{cm}^3$ . An undesirable characteristic of the discharge is the apparent high temperature (a few thousand degrees Kelvin) of the electrons. For this reason, it is planned to try other types of discharges; studies will also be made in the decaying plasma after the discharge has been turned off. The present plasma appears to be adequate for making meaningful studies of electron collision frequency.

#### Initial Probe and Circuitry Completed

The first design for the probe and its required circuitry has been completed and is being evaluated. The frequency shift technique offers the best sensitivity and response time, but bridge measurements also offer some advantages, notably absolute accuracy and convenience.

#### Cylindrical Capacitor:

The probe consists of a cylindrical capacitor for which the walls of the vacuum chamber are the outside cylinder. The chamber is 20 inches in diameter and 30 inches in length. The inner cylinder is made of one inch diameter polished aluminum tubing and consists of three pieces, a center cylinder 40 cm in length and two guard cylinders each 15 cm in length. The capacitance of interest is that of the center cylinder with respect to the chamber. This capacitance is approximately 7.5 picofarads when guarded and 10.6 picofarads when unguarded.



### Oscillator Circuit:

The heart of the frequency shift method is the oscillator, shown in Figure 2, whose frequency is determined by the probe capacitance in series with an inductance. The actual circuit used is essentially the same as that used in recent rocket experiments and consists of a Clapp oscillator circuit. The main advantage of the Clapp oscillator is its excellent frequency stability due to two large capacitors,  $C_A$  and  $C_B$ , which swamp out tube capacities and other stray capacities which are not in series with the inductors. Actually, two inductors are used, so that one inductor can be short-circuited by a relay to provide a change in frequency. In this laboratory version a variety of inductors can be plugged in to provide frequencies from 1 - 10 MHz. The rf voltages applied to the probe can be adjusted between 100 millivolts and a few volts. Also, large dc voltages may be applied to the probe without changing the frequency. The frequency stability of the oscillator has been measured to have a short-term stability of 1 part in  $10^5$  and a long term stability of 1 part in  $10^4$ .

### Guard Amplifier:

The guard amplifier is designed to further reduce the effect of stray capacitance on the oscillator circuit and to provide a guard signal on the guard cylinders. The amplifier output drives the shield of an interconnecting cable and drives the guard cylinders at the same voltage and phase as that applied to the probe by the oscillator. In this manner, the stray capacitance from the inner wire to the surrounding objects is eliminated.

Since the oscillator circuit is sensitive to any capacitive loading, the guard amplifier input must have a very low input capacitance. The amplifier consists of two emitter follower stages connected in series. The input transistor



was selected for low input base to collector capacitance and high frequency response. The complete amplifier circuit has an overall gain of 0.95 with a time lag of 3 to 4 nanoseconds, and an input capacitance in the order of 1 picofarad. These values hold over the complete oscillator frequency range.

#### Auxiliary Equipment:

The remaining circuitry for the frequency shift technique includes a high frequency counter, mixer, stable local oscillator, and discriminator. With the exception of the mixer which has been designed and built in the laboratory, the components listed are standard laboratory equipment and are available at least on a part time basis.

A standard impedance bridge (Boonton Radio Type 250) has already been used, and a sensitive selective voltmeter (Siemens 3D335) has become available for more accurate bridge measurements.

#### Initial Measurements Made in the Plasma

Several experiments have been conducted in the plasma. To show that the plasma parameters are in an experimentally interesting range, measurements of change of capacitance versus discharge current, probe frequency, and probe rf voltage were made using the Boonton Bridge. Figures 3, 4, and 5 show some of the results. Figure 3 shows that the capacitance is larger than the free space value when the plasma current is large (i.e., corresponding to a high electron concentration), and is below the free space value when the current is low (low electron concentration). This behavior is to be expected since the sheath effect with an overdense plasma increases the capacitance, while the underdense plasma may be regarded as a dielectric with relative dielectric constant less than unity. Similarly in Figure 4, the capacitance is seen to vary above and



below the free space value as the probing frequency is varied about the (constant) plasma frequency.

When the probing frequency is well above the plasma frequency the change in capacitance as a function of probing frequency can be plotted theoretically. The dotted line in Figure 4 corresponds to the usual Appleton-Hartree magnetoionic theory which assumes a constant collision frequency in the Boltzmann equation. The solid line represents the generalized magnetoionic theory (e.g. Sen-Wyller) in which the velocity dependence of collision frequency is taken into account. Both theoretical curves were made to fit the experimental points in the 15 MHz to 17 MHz region. It is evident that the generalized theory is in better agreement with the experimental results.

Figure 5 shows the results of the measurement of change in probe capacitance as a function of the rf voltage applied to the probe. It is seen that the applied rf voltage has an appreciable effect on the measurement when its magnitude is a few tenths of a volt.

The high sensitivity at small rf voltages is a big advantage of the frequency shift technique for measuring capacitance changes. The initial probe and oscillator circuitry works well at rf voltages as low as 100 millivolts, and it is believed that refinement of this technique will lower this limit even further.

Some initial measurements of collision frequency have also been made in the plasma using the oscillator described earlier. Because of minor problems encountered, it is too early to use these measurements as significant results. However, the measurements did indicate that there are no major problems which would alter the



experimental method. The probe operated as expected and the results obtained were of the correct order of magnitude. These initial measurements also indicated the probe is sensitive to small changes in electron density and, providing theory is correct, would determine the collision frequency to within a few percent. It is expected that in the next few months, significant measurements will be made and a long term study of the dependence of collision frequency on many various factors can be initiated.

#### High Purity Vacuum System Being Completed

The moveable, high purity vacuum system pictured in Figure 6 is now being completed. It was not built under this contract but will be available much of the time for these studies. The system includes a small roughing pump, and a 2-inch air-cooled diffusion pump with a liquid nitrogen baffle. When completed the system should be able to attain pressures in the  $10^{-8}$  millimeter Hg. range. Although a fourteen inch diameter bell jar and base plate are shown in the picture, these are easily removeable and can be replaced by a totally glass system when extremely high purity is required. This system can be used for many experiments not requiring large volumes and should add to the flexibility of the laboratory.



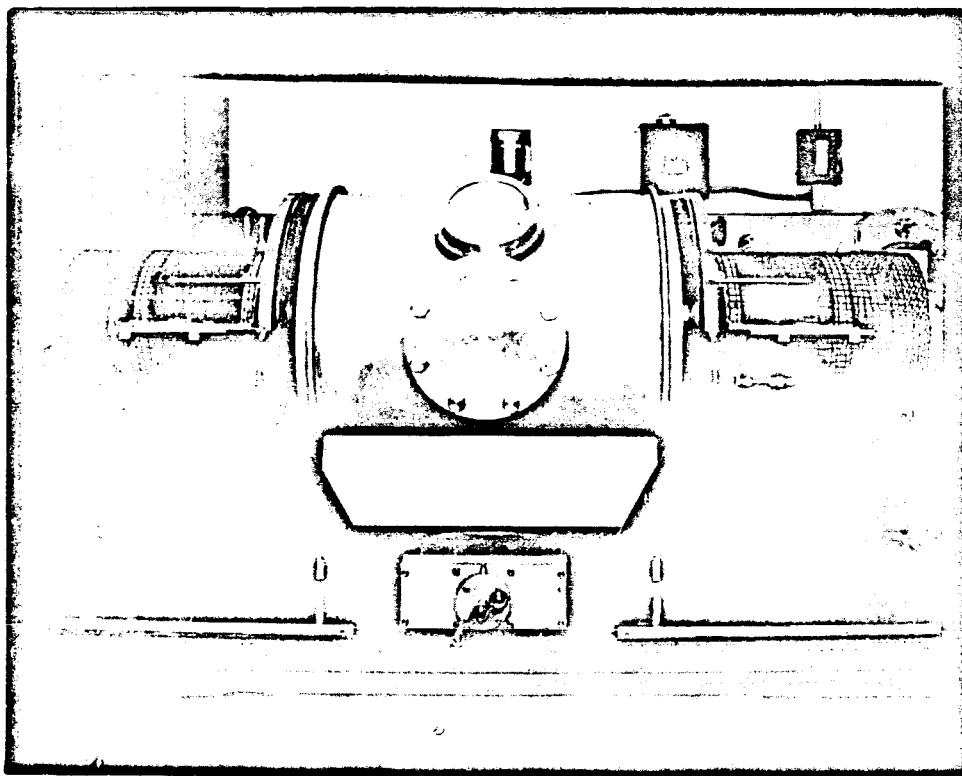
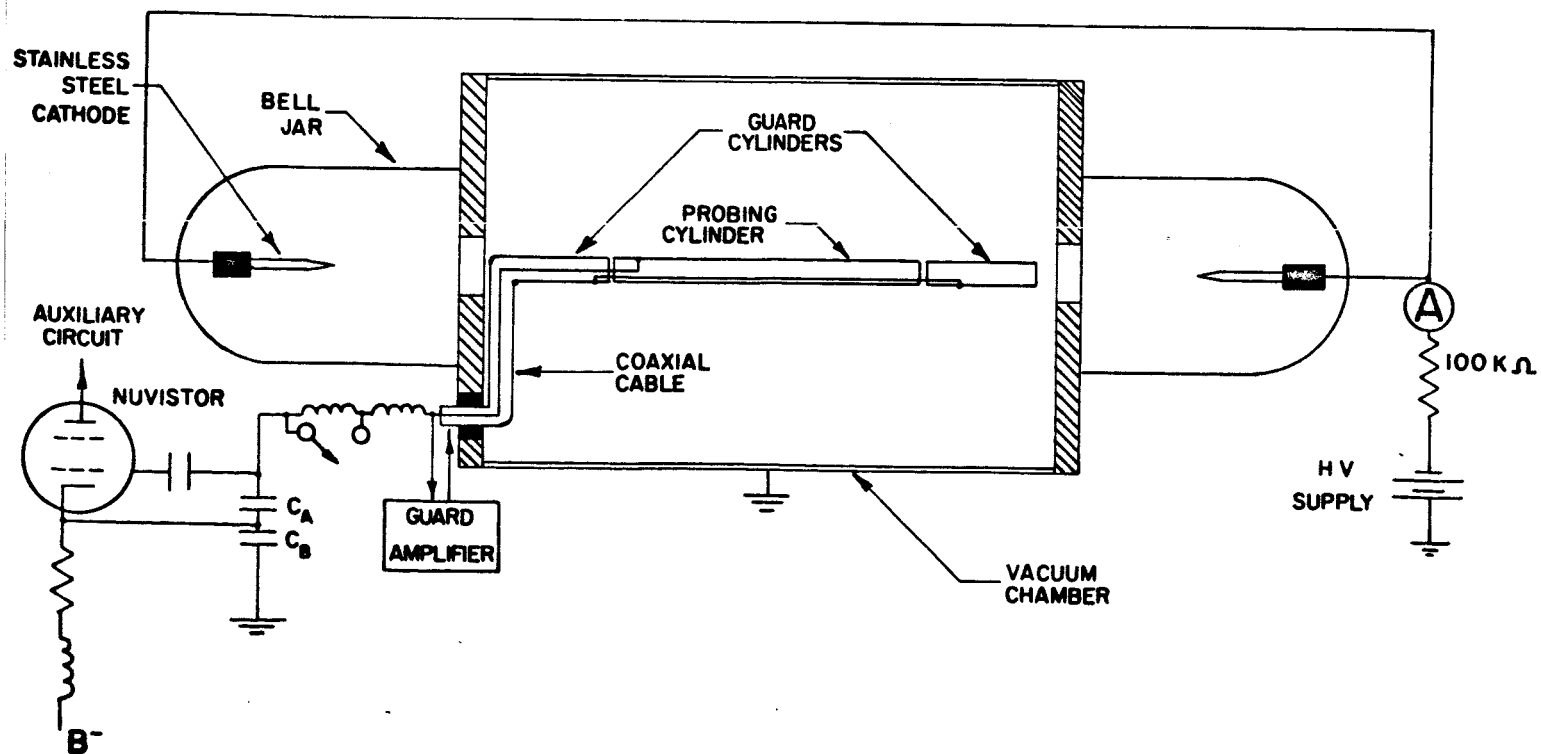


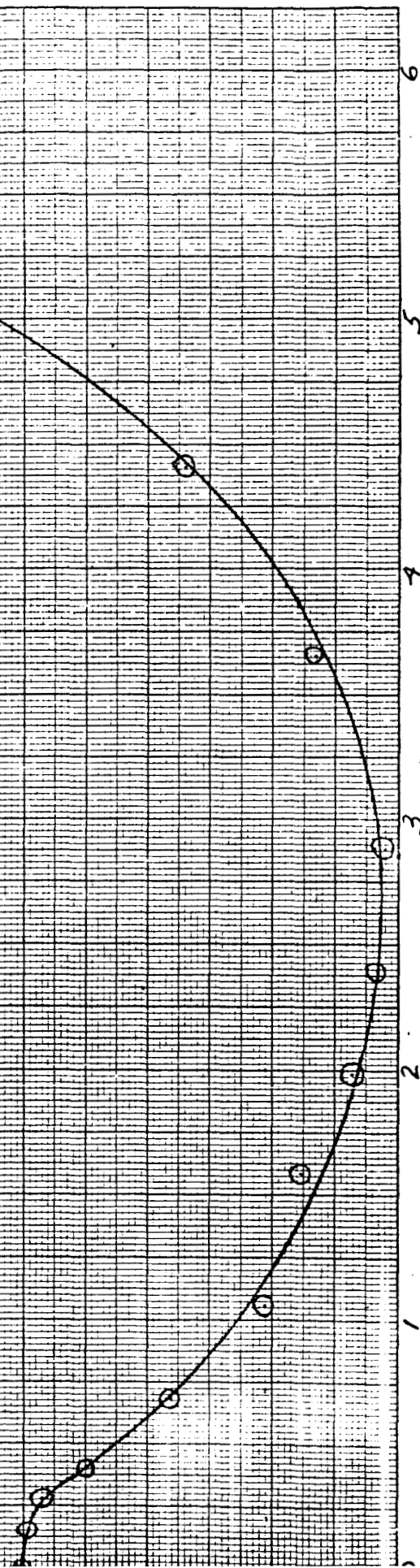
FIG. 1 VACUUM FACILITY





# Change in Probe Capacitance vs. Discharge Current

Measured on Boston Radio Type 250  
 RX Bridge  
 Helium Gas Pressure - 78 microns  
 Operating Frequency - 3 MHz  
 Free Space Capacitance - 10.6 pf





# Change in Probe Capacitance vs Frequency

Measured on Boston Radio Type 250

Rx Bridge

Mercury Gas Pressure - 78 microns

Cathode Voltage - (-1.82 KV)

Discharge Current - (.3 ma)

Grid Space Capacitance - (10.6 pF)

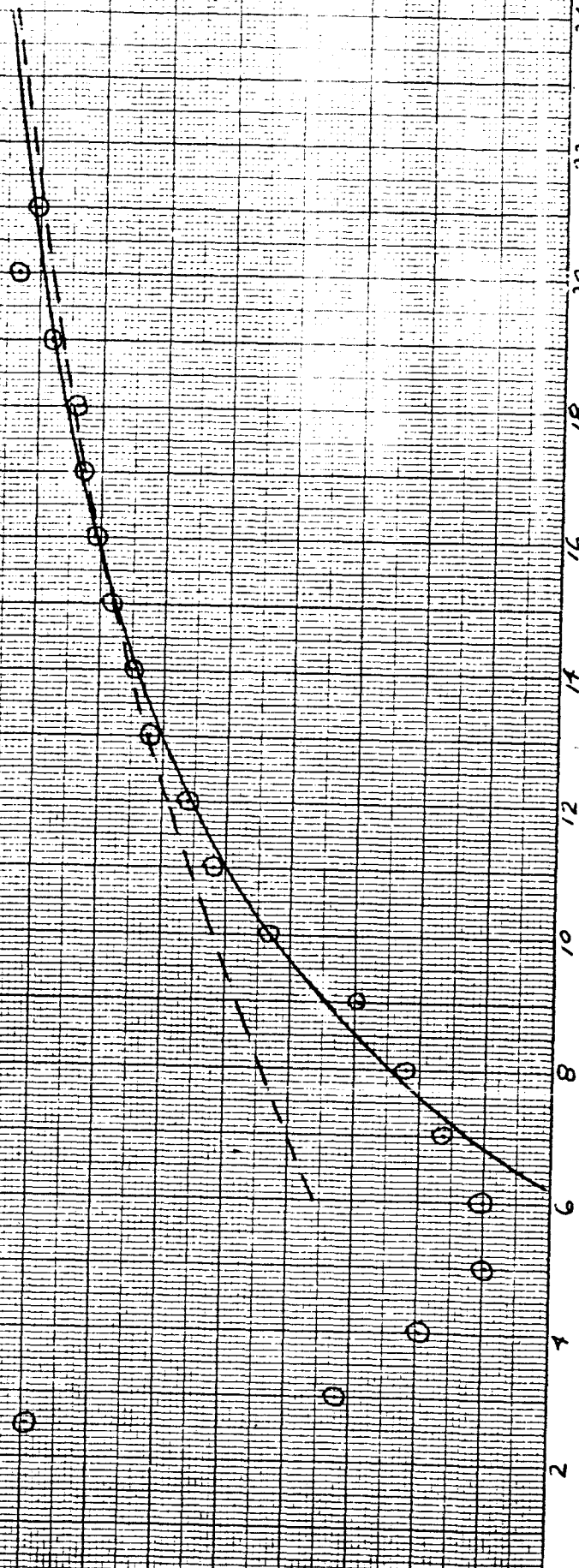
Calculated Plasma Frequency - 7.56 MHz

Corresponding Electron Density -  $7.1 \times 10^{16} \text{ electrons/cm}^3$

Calculated Cutoff Frequency

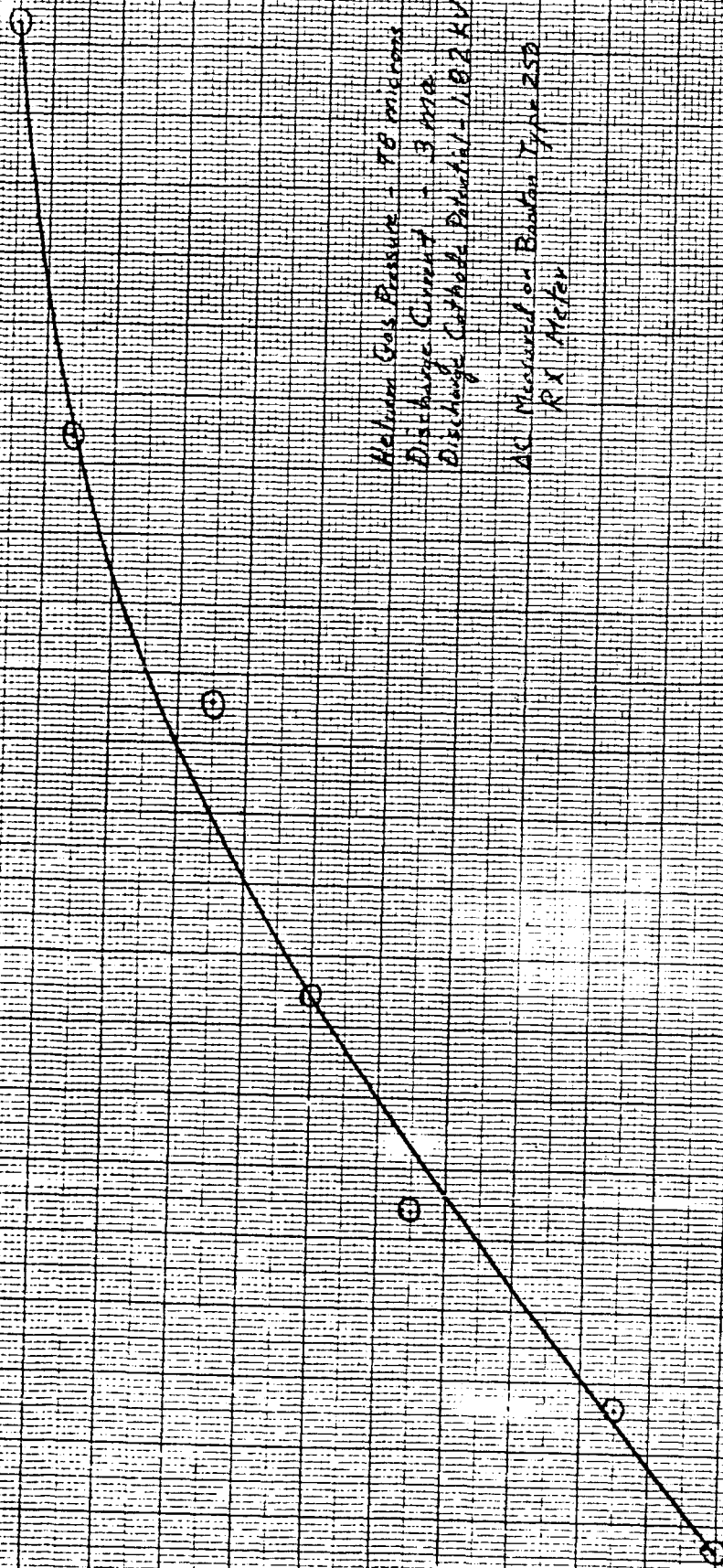
Application: Hartree - 7.8 MHz

See Walter - 26 MHz





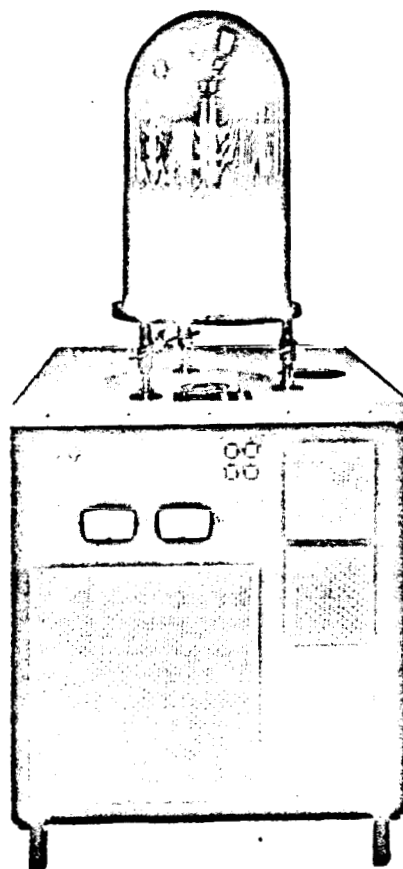
Change in Capacitance  $C_1$  Oscillator Voltage Applied to Probe



Helium Gas Pressure - 78 microns  
Discharge Current - 3 mA  
Discharge Cathode Potential - 10.2 KV

AC Measured on Boston Type 25B  
RX Meter





**FIG. 6 MOVEABLE HIGH VACUUM SYSTEM**